



Green Infrastructure for Sustainable Urban Water Management Experience from five Forerunner Cities

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Green Infrastructure for Sustainable Urban Water Management: Experience from five Forerunner Cities

Li Liu and Marina Bergen Jensen

About this booklet

Title

Green Infrastructure for Sustainable Urban Water Management:
Experience from Five Forerunner Cities

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Preface

This booklet presents findings from the research project “Potential of the eco-city concept globally and in Denmark: A comparative Sino-Danish study with focus on water and urban form.” The study, including this publication, is financed by Realdania and Sino-Danish Centre for Education and Research (SDC). An Advisory Board (see Box 1) with members from Denmark and China has followed the project and contributed with valuable discussions and comments at various stages of the project.

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Li Liu and Marina Bergen Jensen

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Table of contents

Part I: Overview of the study

Looking for inspiration..... 6

Can green infrastructure play a role in urban water management? 6

Transition towards sustainable urban water management..... 8

Is your city a water-sensitive city? 8

Selected forerunner cities and study methods 9

Summary of the main findings10

References Part I13

Part II: City profiles

Singapore16

Berlin 20

Melbourne..... 24

Philadelphia..... 28

Sino-Singapore Tianjin Eco-city 32

Part I:

Overview of the study

Looking for inspiration

Sustainable urban development has been prioritized in Denmark for many years. Danish cities strive to play a pioneering role in creating and applying green solutions for urban water management. To better reflect on and orient Denmark’s practices, an international outlook may provide valuable knowledge and surface new best practices. Thus, we have studied the practices of five forerunner cities around the world that are renowned for their progressive approach to one or more aspects of urban water management. The five selected cities are Singapore, Berlin, Melbourne, Philadelphia, and Sino-Singapore Tianjin Eco-city (Figure 1). Presented from a social-technical perspective, this booklet provides insights into the role of green infrastructure in urban water management and details green infrastructure solutions employed in these cities, as well as barriers to implementing these solutions.

Can green infrastructure play a role in urban water management?

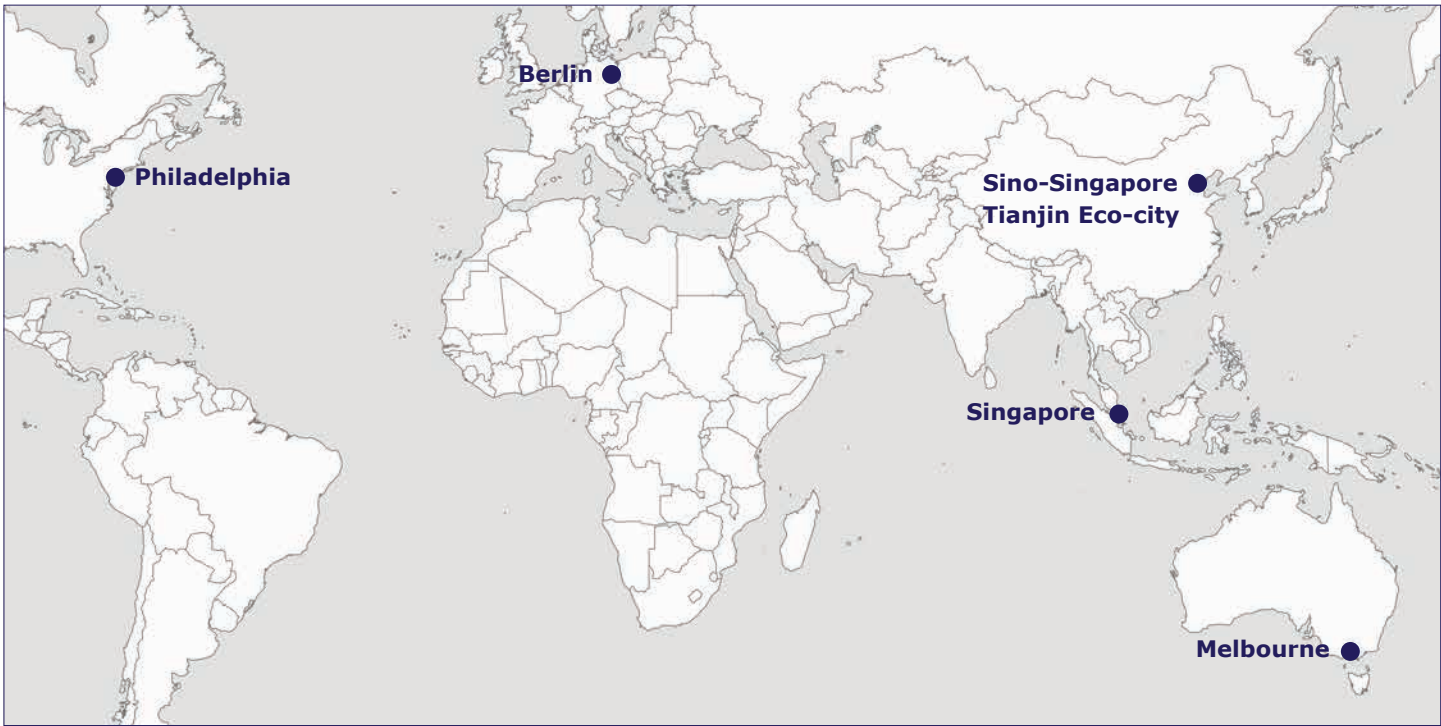
Cities are critical hot spots, simultaneously adding to environmental and climatic challenges facing today’s global society

while acting as essential drivers of future solutions [1]. In the case of freshwater management, cities play a significant role; to various degrees, they impact both water quantity and quality through land-use choices, overexploitation, and contamination. Wong and Brown [2] suggest that to achieve sustainable urban water management, cities must give water due prominence in urban development. This requires integration of the urban design process with other disciplines responsible for provision of water services. Cities also need to improve the social-political capacity of managing water and develop sustainable behavior regarding citizens’ interactions with water. Future urban landscapes need to capture opportunities and technologies to maintain the resilience of cities with regard to the impacts of climate change, which have already created weather extremes and uncertainties in urban water supplies. Planning should improve ecosystem services that protect downstream aquatic environments and other ecological habitats. Thus, urban landscapes must, beyond providing spatial amenities, prioritize ecological functions that facilitate processes such as evaporation, transpiration, and infiltration.

From linear to circular and equitable

The emerging tendency in developed cities to resort to urban landscaping to

Figure 1. Locations of the five cities investigated as forerunners in sustainable urban water management (figure created by Christian Fertner).



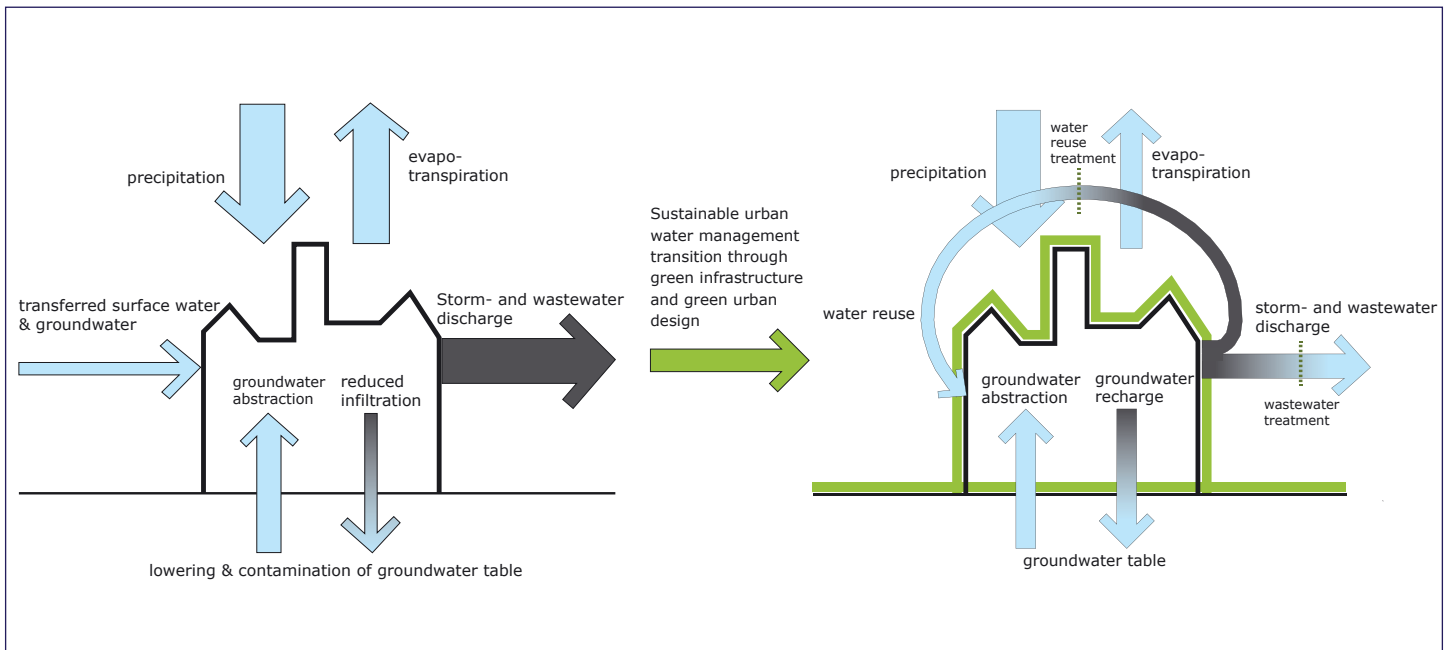


Figure 2. From linear to cyclic approach to urban water management by green infrastructure and green urban design.

accommodate urban water management is embodied in various terms such as sustainable urban drainage systems, low-impact development, water-sensitive urban design, and sponge city [3]. The common concept behind these terms is the use of the urban landscape in transforming the linear character of conventional urban water management methods into a more cyclical approach in which water supply, drainage, and ecosystems are treated as part of the same system, mimicking natural water flows. Figure 2 illustrates on the left the typical situation with linear supply and drainage systems that are 100% separated. To the right is a circular water system where storm- and sewage water are included in the supply. The extraction of groundwater is in equilibrium with groundwater recharge. The part of the urban landscape providing ecosystem services is often referred to as green infrastructure, defined as “an interconnected network of natural areas and other open spaces that conserves natural ecosystem values and functions ... and provides a wide array of benefits for people and wildlife” [4]. Green infrastructure is a critical part of the urban landscape intended to optimize the above-mentioned ecological functions.

Making water and green win-win

Sustainable urban water management in urban landscapes may provide several key sustainability improvements for cities [5]: (1) improve urban drainage by ensuring

control of pluvial flooding; (2) improve quality of discharged water by separating stormwater runoff from wastewater, thus limiting number of combined sewer overflows and reducing load at municipal treatment plants; (3) reduce the water footprint¹ of a city by linking stormwater management to water supply by means of stormwater harvesting and groundwater recharging; (4) increase livability and social-economic sustainability by introducing well-designed stormwater management features that improve aesthetics, recreation, and social inclusiveness, provide vegetated surfaces that improve air quality, reduce urban heat islands and noise effects, provide areas for urban farming, etc., and by creating new implementation and maintenance jobs; and (5) increase biodiversity and ecological performance, conserve regional ecosystems by designing stormwater management features that compensate for loss of nature caused by urbanization, and minimize the negative impact of discharging contaminated urban drainage into receiving water bodies.

¹ Water footprint includes water used directly (e.g., from a tap) in the city and water used outside the city for producing food and products transported to and consumed by the city, so-called virtual water. Virtual water usually makes up the majority of a city's water footprint. In this study, only water used directly is considered.

Transition towards sustainable urban water management

A social-technical perspective is useful in understanding the complex process of transition that large urban water systems need to undergo to become sustainable; one such perspective is the multi-level perspective [6][7]. Multi-level perspective operates on three levels (Figure 3). The landscape is the ‘macro-level’ and refers to the environmental, social-political, and economic pressures acting on the system; in the current context, these pressures include climate change, urbanization, and public requests for increased livability.

The regime is the ‘meso-level,’ referring to the configuration of responsible institutions and the physical infrastructure for which they are responsible. In the case of water systems, the meso-level includes water authorities and utilities, as well as infrastructure, including pipes, pumps, treatment plants, and storage facilities. The regime operates according to its sanctioned discourse, which is controlled by the cognitive, normative, and regulative conditions, or ‘pillars,’ sustaining the regime. The niche is the ‘micro-level,’ and it encompasses innovations and alternative approaches [8].

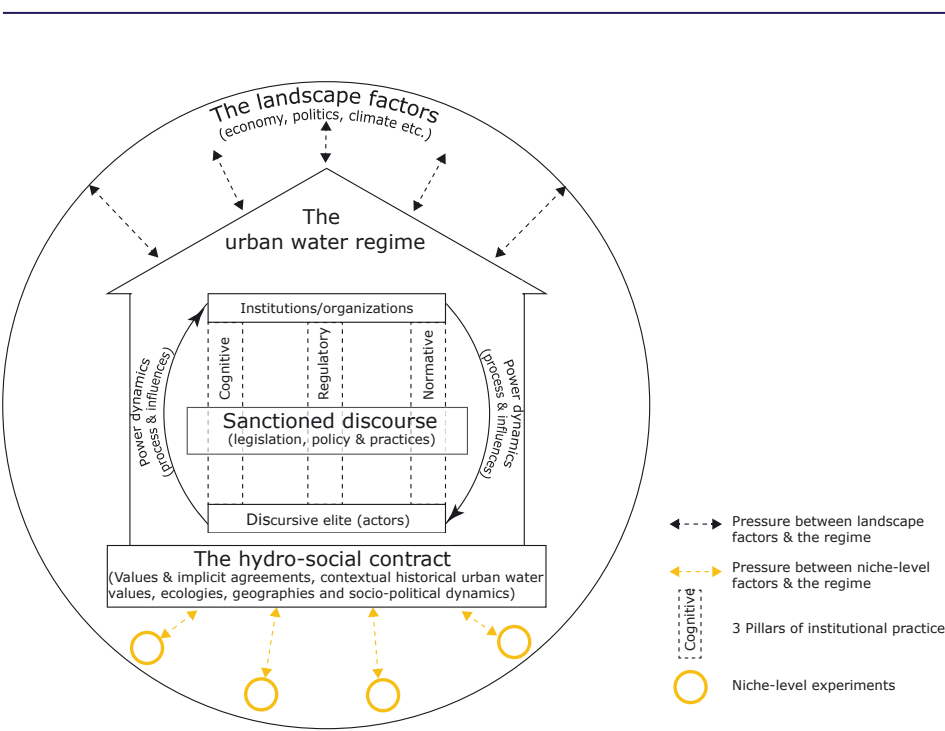
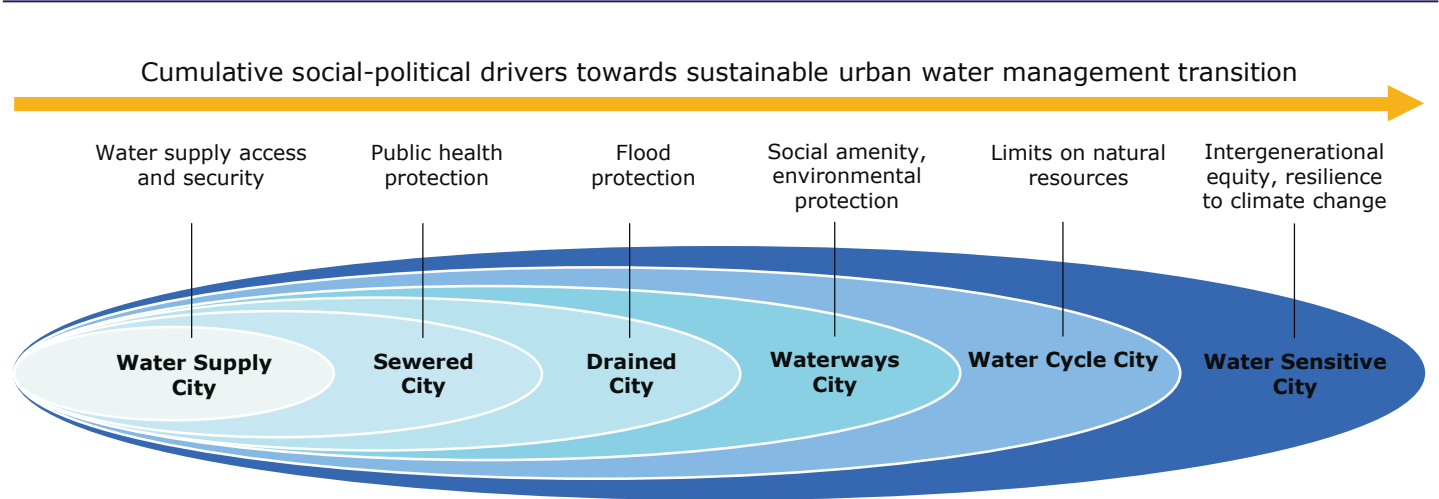


Figure 3. The operation of multi-level perspective in the urban water regime . The regime, which ensures the city’s water supply and drainage, is shown as a house. The roof is carried by three pillars in terms of knowledge, norms and rules. The foundation is the contract the regime has with the society. The house is in a landscape (circle) where conditions can arise that push the regime to change the way things are done. New solutions can be developed and tested by players outside the regime (including abroad) and within the regime. They are called niches as long as the solutions are not parts of the regime practice. (Mguni et al., 2015).

Figure 4. Hypothetical transition pathway toward sustainable urban water management (adapted from Brown et al., 2009). Water Supply City = city with water supply system. Sewered City = city with sewage system. Drainage City = city with drainage system for stormwater. Waterways City = city with a clean and recreational aquatic environment. Water Cycle City = city with recycling systems. Water Sensitive City = city with systems that are robust against climate change and can also provide future generations with water.



The emerging green infrastructure approach to urban water management can be considered a niche-level perspective. For this approach to become the new sanctioned discourse in a transition toward sustainable urban water management, practices must shift within each of the three regime pillars [9].

Is your city a water-sensitive city?

To better describe the level of transition of cities towards sustainable urban water management, Brown et al. [9] proposed a framework based on research into the historical development of the hydro-social contracts of Australian cities. This framework includes six states of progression: water supply city, sewerage city, drained city, waterways city, water cycle city, and

water-sensitive city (Figure 4). The first three states refer to a transition path already completed in most developed cities; the last three states represent the desired transition path towards sustainable urban water management. A waterways city integrates water as an important aesthetic and recreational feature; eco-technologies and other measures are therefore necessary to protect receiving waterways from diffuse-source stormwater pollution. A water cycle city links environmental protection, water supply security, public health protection, and flood control. The ultimate state, a water-sensitive city, includes intergenerational equity, ecological integrity, and climate change resilience. Although direct comparison between cities is difficult, and perhaps irrelevant due to differences in hydro-social contracts and landscape pressures (from the multi-level perspective), the framework offers an opportunity to learn from a view encompassing multiple cities.

	Singapore	Berlin	Melbourne	Philadelphia	Tianjin Eco-city
Area (km ²)	719	899	37.6	367	34
Population (millions)	5.6	3.5	0.13 (2015)	1.6 (2013)	0.35 (planned)
Water system characteristics	Precipitation 2343 mm; limited land as water catchment; lack of groundwater reservoir; flooding, sanitation, and pollution in earlier years	Precipitation 600 mm; no major river for water supply or diluting wastewater; combined sewer overflow to rivers	Precipitation 650 mm; saline and shallow groundwater; climate change decreases available natural water resource; heat wave and 13 years' drought	Precipitation 1055 mm; legislation and policy at the state level require combined sewer overflow control to protect water quality of surface waters	Precipitation 603 mm; saline soil and saline groundwater; large artificial green areas and wetlands; high ambition for livability while conserving resources
Characteristics as study case	Urbanized island state with limited land for catching water for supply in relation to population; still aiming at self-supply water	Capital city with opportunity to import water from exurban areas but chose to self-supply water within city limits	Located on the coast downstream of a river catchment; groundwater not suitable for supply; urban stormwater runoff damaging freshwater ecology; aiming at sustainable urban water management	Renowned for advanced stormwater management policy (built upon those of Portland and Seattle) to reduce combined sewer overflow required by Federal Clean Water Act	Built on wasteland; water supplied from neighboring city; high ambition for water reuse primarily to maintain artificial green-blue areas
Main references, informants (*) and documents	[11]; [12]; [13]; [14]; * at PUB (Singapore's National Water Agency); * at NParks (Singapore's National Parks Board)	[15]; [16]; [17]; * at BSETCP (Berlin Senate for Environment, Transport and Climate Protection); * at BSUDH (Berlin Senate for Urban Development and Housing)	[18]; [19]; [20]; * at City of Melbourne	[21]; [22]; [23]; [24]; * at PWD (Philadelphia Water Department)	[25]; [26]; * at SSTECCB (Sino-Singapore Tianjin Eco-city Construction Bureau); * at the Eco-city's construction-projects management company

Selected forerunner cities and study methods

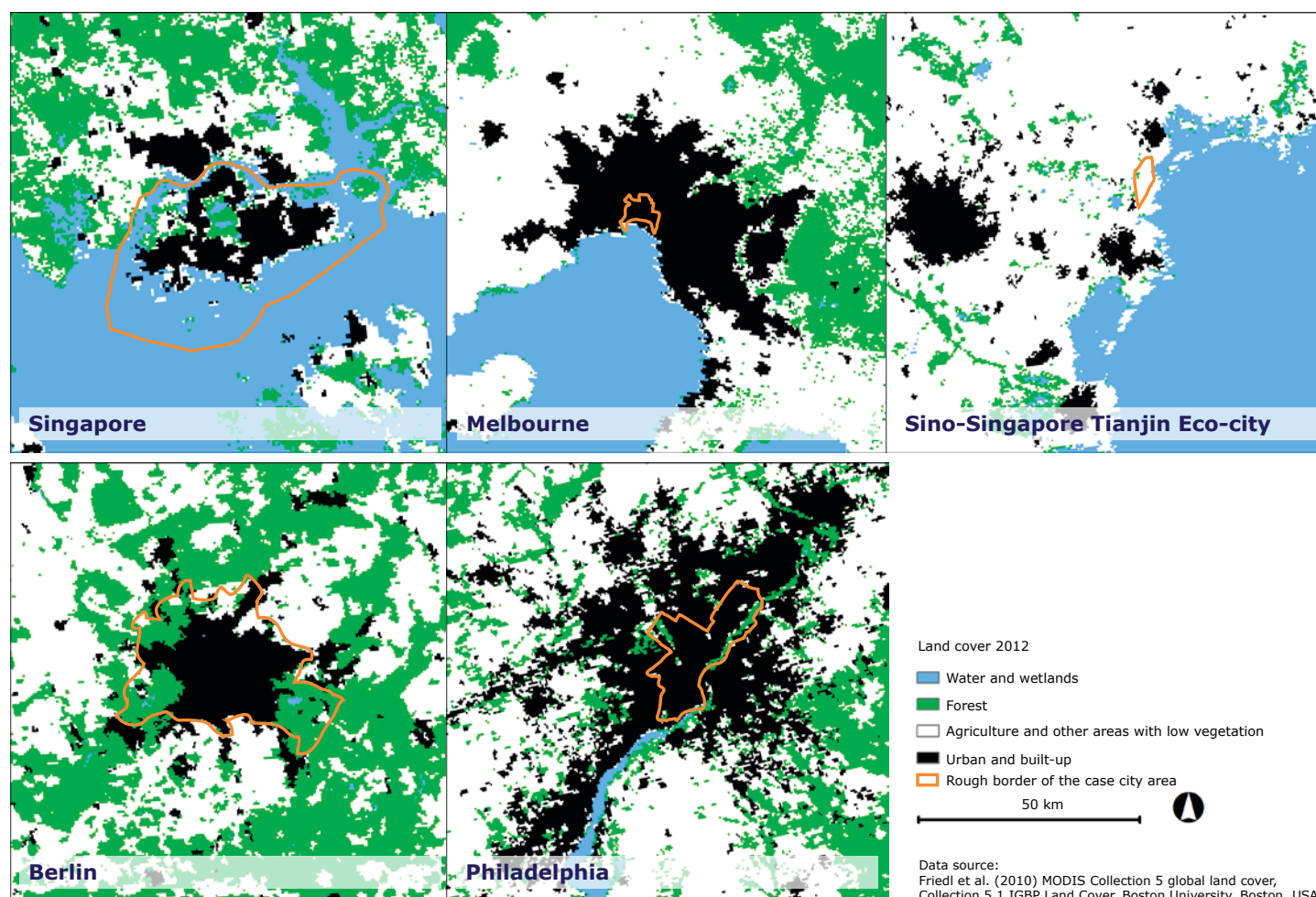
From a list of potential case cities generated from open sources, literature, international conferences, and personal networks, four existing cities—the city-state Singapore, Berlin in Germany, Melbourne in Australia, and Philadelphia in the United States—and one newly built city—Sino-Singapore Tianjin Eco-city in China—were selected. These cities are renowned for being progressive in one or more aspects of sustainable urban water management. The five cities represent a broad geographical distribution in economically wealthy cities. Additionally, data were accessible for these cities. Table 1 presents a basic overview of the five cities and their characteristics as study cases. Figure 5 provides an overview of the spatial characteristics of these five cities.

Data were first collected from open sources, including the case cities' official

websites, published plans and documents, and articles. To validate data and obtain practice-based information, an online questionnaire was distributed to relevant city managers of each city during spring and summer 2015; questionnaires were followed by interviews and emails when clarification was needed.

In total, eight city managers contributed. Data analysis was based on the multi-level perspective framework described above. Landscape factors included water system condition and challenges. A regime's sanctioned discourse was revealed as specific goals for urban water management together with strategies and practices of green infrastructure-based water management. Niche-level perspectives were considered as reported measures of and barriers to implementation of green infrastructure. The transition status of each city was determined by comparing the cities' strategies and practices with the description of the sustainable urban water management transition process provided by Brown et al. [9].

Figure 5. The five case cities' spatial relation to their city regions (figure created by Christian Fertner).



Summary of the main findings

Major water challenges of cities drive their green transition

All five cities faced challenges to their water supply or to the environmental protection of their surface waters. Risk of flooding appeared as only a minor or emerging threat. The goals for urban water management mirrored the challenges. Singapore and Berlin use green infrastructure on a large scale to collect and treat stormwater runoff and reclaimed water for water supply purposes. Philadelphia aims to improve surface-water quality by using green infrastructure. Melbourne and Tianjin Eco-city irrigate public green spaces with non-conventional water to reduce potable water consumption.

Green infrastructure can play an active role in the transition to sustainable urban water management

Green infrastructure plays a relatively strong role in these forerunner cities in the transition to sustainable urban water management. Although green infrastructure today plays a role in only some aspects of urban water management – predominantly water supply and environmental protection – the mindset of the responsible parties indicate that the regimes of these cities are open to further adoption of green infrastructure approaches.

Overall, green infrastructure is used as catchment and features, to store, harvest, and cleanse stormwater for the public supply, and to improve the local water balance. The largest green infrastructure solutions observed for each city were Singapore's reservoir and river parks for water supply, flood control, and recreation (Figure 7), Berlin's river-bank filtration systems, Melbourne's zero-potable-water-use parks for conserving potable water, and Tianjin Eco-city's manmade wetlands for water cleansing and scenery (Figure 28).

In general, green infrastructure has the potential to integrate water supply and flood control with livability, biodiversity, and ecological performance, especially as flexible decentralized water-collecting and water-consuming elements. Green infrastructure contributes to handling stormwater at the source and reducing

water demand while improving water supply. In addition, the amenities, recreational opportunities, and cultural values provided by green infrastructure support green identity and growth by drawing new customers and retailers, creating additional local green jobs, and increasing property values.

However, only cities experiencing significant supply challenges or demonstrating high ambitions for water self-sufficiency had implemented green infrastructure for water management on a larger scale. As none of the case cities have been subject to severe flooding and stormwater management for reducing flood is still mainly at strategic level, it is difficult to see to what extent green infrastructure-based stormwater management could reduce urban flooding and to what extent flood control could be linked to water supply issues.

Various measures for upscaling green solutions are applied

All five cities have city-wide strategies for scaling up green infrastructure solutions to cover the entire city, and all have implemented pilot projects, particularly on public land.

Motivation for ongoing changes came from within the regime, mainly under the pressure of various landscape factors. This has forged a relatively strong collaboration among water, green space, and planning sectors within city administrations. City administrations initiated programs, regulations, guidelines, and incentives to engage the private sector and citizens in the development and implementation of niche innovations, which encourages a sense of shared responsibilities.

Barriers to implementation call for social-technical innovation

Severe institutional barriers to the implementation of green infrastructure-based urban water management have been experienced by all five cities. Barriers range from difficult cooperation among sectors and stakeholders to a lack of local experience in developing and maintaining green infrastructure-based stormwater management elements. Most cities also shared barriers related to space and cost constraints. Successful breakthroughs seem to rely on innovation and the ability to reverse conventional ways of designing

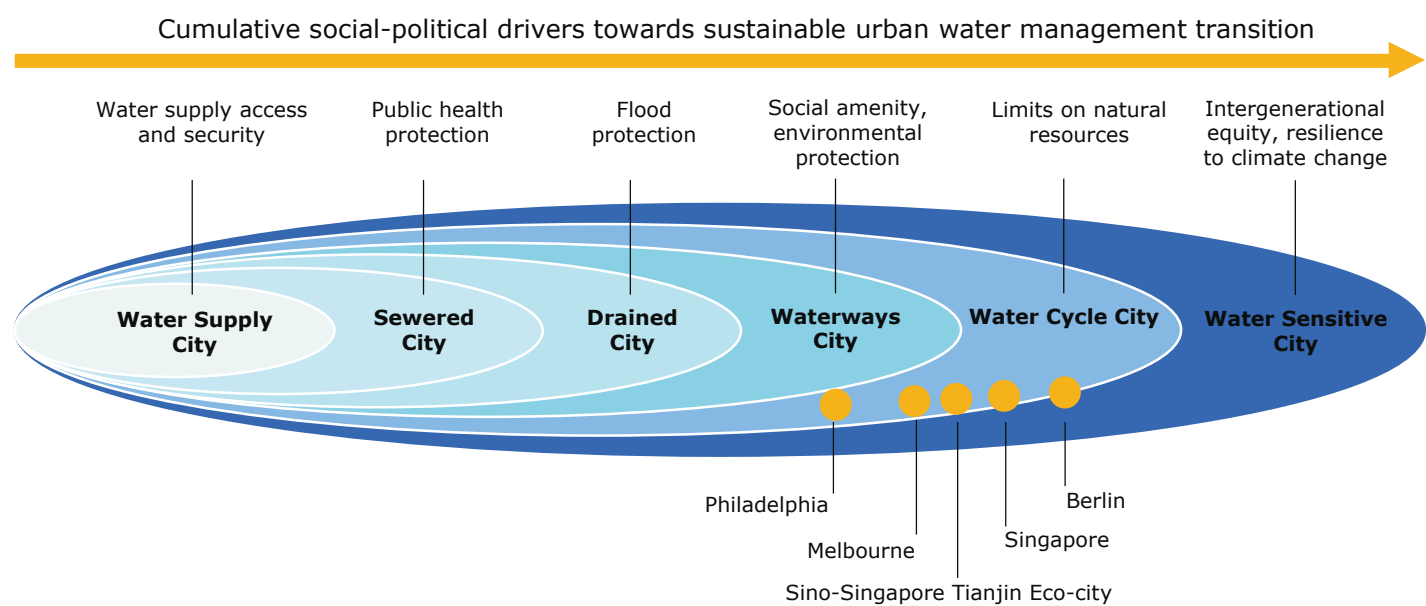


Figure 6. State of each of the five case cities based on the sustainable urban water management transition pathway of Brown et al. (2009).

and managing urban spaces and structures, as well as establishing a way to learn from practical experiences with new approaches through iterations of testing and improvement. Earlier studies indicate that to overcome institutional barriers and facilitate sustainable transition and implementation, many aspects of inter-institutional and public-private collaboration must be improved. Ways to do this include clearer responsibilities among regime institutions, favorable conditions for developing accountability and collective responsibility, and improved incentives, procurement rules, and municipal decision-making processes for public-private collaborations [27] [28].

If sufficient time is allowed for gaining experience, developing knowledge and innovation, and updating regulations, urban water management via green infrastructure could mature [6]. However, time is a critical factor due to the speed of both urbanization and climate change.

Under this time pressure, cities need to specifically identify the factors causing the lag in transition and find counter-measures to speed up the transition to sustainable water management.

A sustainable urban water management transition frame can inspire cities' green transition

None of the five cities in this case study can be defined as a water-sensitive city as defined by Brown et al. [9]. Rather, all cities qualify only as waterways cities, moving toward the water cycle city, or as water cycle cities (Figure 6).

However, the city profiles differed with regard to their status as a water cycle city. Berlin is a full-scale water cycle city, largely based on their green infrastructure approach, and Singapore is well on its way. Melbourne and Tianjin Eco-city have adopted policies for improving local water balance but they still depend strongly on water resources originating outside the city. Philadelphia does not have a clear goal of striving for the state of water cycle city. None of the cities could be characterized as approaching water-sensitive city, as striving towards climate resilience is still a rather new goal. Despite their different stages within this transition, green infrastructure as a discourse played a strong role in sustainable urban water management transitions for all five cities.

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Part II:

City profiles



Urban water management

Surrounded by sea water, the freshwater resources of Singapore are especially precious, despite the region’s plentiful rainfall. The water system in the area is constrained by the limited and densely settled land area available to catch and store rainfall and the absence of natural aquifers and lakes. To strengthen its water security, Singapore has over the last 50 years developed a diversified and robust water supply through four water

sources, called the Four National Taps: local catchment water, imported water, reclaimed water (NEWater), and seawater desalination. Currently, stormwater run-off from two-thirds of Singapore’s land area is stored in 17 reservoirs for water supply. Singapore also imports water from Malaysia under a 1962 agreement between Singapore and the Johor State Government. Advances in membrane technology have made it possible to treat wastewater and stormwater collected in urban catchments to World Health Or-

Figure 7. Overview of Singapore’s Marina Barrage and Marina Reservoir, combining the utility function of alleviating floods and supplying water with social-cultural functions of providing attractions and recreations, by redesigning the barrage into a popular park.

Country & city status	City-state of Singapore
City area (km²)	719
Population (millions)	5.6 (2015)
GI and open space coverage	10% parks and natural reserves
Annual precipitation (mm)	2343; distributed evenly throughout the year
Main surface water & role for supply	Two-thirds of Singapore’s land area is water catchment
Honors on sustainability	1st place among 22 major Asian cities in Siemens’ Green City Index for Asia in 2011 4 th place in 2014 in the United Nation’s Environmental Performance Index

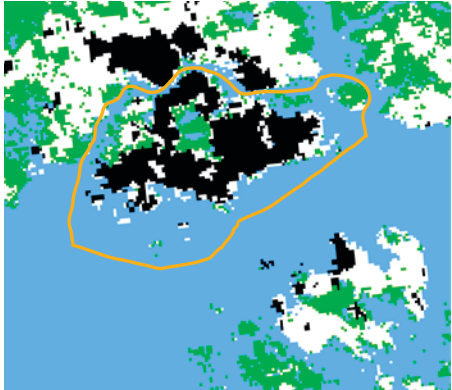


Illustration: Christian Fernet



Figure 8. Kallang River, Bishan-Ang Mo Kio Park. The park has been redesigned to allow the channelized Kallang River to become naturalized with fluctuating water levels allowing for a larger flow and meanders, adding to the quality of the park.

	2015	2030	2060
Domestic water consumption (liter per capita per day)	151 (in 2012)	140	-
Water demand (millions of liters per day)	~1995	Increase 25%	Almost double
Water demand: Domestic sector/ non-domestic sector	45/55	40/60	30/70
Local catchment water (% of land area)	67%	No specified goal	90%
NEWater capacity (% of total supply)	30%	50%	55%
Desalination capacity (% of total supply)	25%	30%	30%

Table 2: Status and goals of the four water taps (Our Water our future, 2013).

ganization (WHO) drinking water standards. NEWater was introduced in 2003 and is used primarily for industrial and cooling purposes. During dry seasons, NEWater is also used to top up reservoirs and is mixed with the raw water intake at waterworks. PUB, Singapore's National Water Agency, is the only water agency. It manages water supply, water catchment, and used water in an integrated way.

Current water challenges

- With continued economic and population growth, water demand is expected to increase. While the city continues to put in place water infrastructure ahead of demand, there is also a need to manage water demand to ensure sufficient water supply.
- The local weather has become more erratic, with dry spells spanning several weeks; in addition, more intense cloudbursts threaten to overwhelm the drainage systems.

from PUB's supply by encouraging seafront companies on Jurong Island to use seawater, instead of freshwater, for cooling processes.

- "Desalinate more seawater": The city will continue investing in research and technology to find better and less expensive methods of desalination.
- The city will integrate the functionality of water catchment with improvements in the economic and environmental status of the city, for instance, by adding to the city's amenities and identity by creating new leisure and recreational spaces and opportunities.
- To prepare Singapore for further weather changes, the city has begun to assess the impacts of climate change on its water services and infrastructure and will implement adaptation measures, such as increasing the capacity of weather-resilient sources like NEWater and desalination.
- To enhance flood protection, PUB has adopted a holistic "Source-Pathway-Receptor" approach to managing stormwater, addressing not just drains and canals ("Pathways") that convey stormwater, but also areas that generate runoff ("Source") and where floodwaters may flow ("Receptors").

Major strategies for urban water management

Singapore's approach to water supply includes the following (see also Table 2):

- "Collect every drop of water": The city plans to expand Singapore's water catchment from two-thirds to 90%.
- "Reuse water endlessly": Water can always be reclaimed and retreated so that it can be used again. To increase the recycling rate, the city will further close the water loop by reclaiming used water from industrial sources for non-potable use, increase water recovery from water reclamation and NEWater treatment, and reduce losses

Green infrastructure approach to water

Green infrastructure plays a relatively strong role in urban water management. Singapore applies an integrated approach to water and urban planning. Green infrastructure is regarded as able to improve water quality by using various natural retention and cleansing features and to

reduce the peak flow of runoff. It helps to create interesting leisure places, integrating the green with the blue.

The Active, Beautiful, Clean Waters (ABC Waters) Programme

Over the years, Singapore has developed a pervasive network of, as of 2006, about 8000 km of waterways and 17 reservoirs. The Active, Beautiful, Clean Waters Programme was launched in 2006 with the aim of redesigning Singapore's waterways and reservoirs beyond their utilitarian functions so that they contribute to urban livability in wider terms. The ambition is to obtain beautiful and clean streams, rivers, and lakes and a vibrant city, referred to as the City of Gardens and Water. More than 100 locations have been identified for potential redesign by 2030. Bringing citizens and communities closer to water increases their awareness of and engagement with water, and thus they can better cherish surface waters and participate in keeping them clean. The ABC Waters Design Guidelines were released in 2009 and have been continuously updated. The current version prescribes raingardens, bio-retention swales, detention ponds, green roofs, and wetlands for on-site detention and retention of stormwater runoff. PUB collaborates with the National University of Singapore to further develop the ABC Waters Programme to better suit the local context. In 2010, PUB launched the ABC Waters Certification to provide recognition to public agencies and private developers who apply the ABC Waters concepts and incorporate ABC Waters design features into their developments. These projects are known as "ABC Waters certified" projects.

Managing stormwater at the source

Singapore's Code of Practice (COP) on Surface Water Drainage, revised in 2013, requires developers to implement on-site detention or retention measures to reduce peak runoff from developed areas into the public drainage system. Development sites of 0.2 ha or larger are required to implement measures such as detention or retention tanks and/or ABC Waters design features to control run-off discharge. These measures may be located on top of buildings, at ground level or underground, or under amenity spaces such as playgrounds and carparks. If ABC Waters design guidelines are followed, the detention and/or retention elements



Figure 9. Sungei Tampines. Green areas have now replaced the earlier concrete river banks and new paths and squares provide the residents possibility to be closer to water.

not only contribute to meeting the COP requirement to reduce peak runoff from developed areas into the public drainage system but also provide some cleansing of the detained stormwater at-source before they are discharged into public waterways or reused. For example, a raingarden can cleanse rainwater before it is collected in a rainwater harvesting tank at the development for non-potable use.

Implementation of and barriers to green measures

Singapore implements green infrastructure primarily through the ABC Waters Programme, ABC Waters Design Guidelines, and the Code of Practice on Surface Water Drainage. Demonstration projects are combined with research and development into new urban planning initiatives, designs for high-density living, and local applications of ABC Waters design features. The experience and knowledge gained from these demonstration projects are used in later projects. The various public agencies have worked closely



Figure 10. Sengkang Floating Wetland sitting within Punggol Reservoir. The wetland is expected to cleanse the water and provide a habitat for birds and fish. The idea of the boardwalks is to bring people closer to the water in order to better enjoy the scenic views and learn about the wetland ecosystem.

together for many years. A no-wrong-door policy was reinforced in 2004 to encourage governmental administrations to handle public enquiries seriously first within the administration that received the enquiries and to share and understand the responsibilities of other sectors. Through collaboration on the ABC Waters Programme, PUB and other agencies such as the National Parks Board, Urban Redevelopment Authority, and the Housing and Development Board have developed a better mutual understanding and better working arrangements. The public agencies lead research and pilot test innovative ideas, as well as developing many green incentives and policies. PUB also encourages external landscape practitioners to innovate and generate new ideas for green urban water management. In the early 2000s, a paradigm shift in water governance positioned the public as the guardians of water resources. Water bodies were opened up for community and recreational use, and more emphasis was placed on engaging the public to experience water and learn about the importance of water. A 3P (public-private-people) network was formed to steer water organizations interacting with broader non-governmental stakeholders. Singapore has also fostered a greater focus on public engagement surrounding construction projects since the early 2000s.

Major implementation measures

- ABC Waters Programme and ABC Waters Certification. As of 2016, 41 Projects are ABC Waters Certified

- Development of guidelines, such as the ABC Waters Design Guidelines
- Revision of the Code of Practice (COP) on Surface Water Drainage
- Cross-sector efforts and stakeholder involvement through programs, COPs/guidelines, demonstration projects, awareness-raising campaigns, and awards

Identified barriers to implementing green measures

Technical barriers

- Water infrastructure and other city facilities and amenities compete for limited space.
- Green measures are usually hard to control and may be viewed as expensive and thus given lower priority compared to more technical initiatives.
- Finding sufficient space within the city to implement these features.
- Developing design guidelines and innovations that can work in the local environmental conditions.

Institutional barriers

- Inter-agency boundaries restrict collaboration on special water management policies and projects.

Although green infrastructure solutions are usually more effective when they are top-down political decisions from superior administrations, through their experiences with ABC Waters projects, the main city administrations and agencies have become more receptive to working together.

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Berlin

Figure 11. Roof greening at Potsdamer Platz.

Urban water management

A closed urban water cycle

Berlin’s supply water is sourced within the city through a water system that has existed since the end of the nineteenth century. In 2000, the Senate of Berlin updated local legislation based on German Water Legislation, which requires water supply to be located near the site of consumption, to emphasize the abstraction of supply water within city boundaries. Raw water intake to waterworks is abstracted

from deep wells with a combination of bank-filtrated river water (54%), artificially recharged river water (14%), and natural groundwater recharge from precipitation (32%). The natural groundwater recharge rate of up to 200 mm per year is not sufficient to maintain groundwater resources. Therefore, groundwater recharging is artificially enhanced through river bank filtration and artificial river water recharge. The intake of raw water balances the recharging of rivers and groundwater. To secure the water quality

Country & city status	Capital of Germany
City area (km²)	899
Population (millions)	3.5 (2010)
GI and open space coverage	44%
Annual precipitation (mm)	600; distributed evenly throughout the year
Main surface water & role for supply	River Spree and River Havel; rivers not a direct source of water supply
Honors on sustainability	Above average performance in German Green City Index; the only German city member of G40

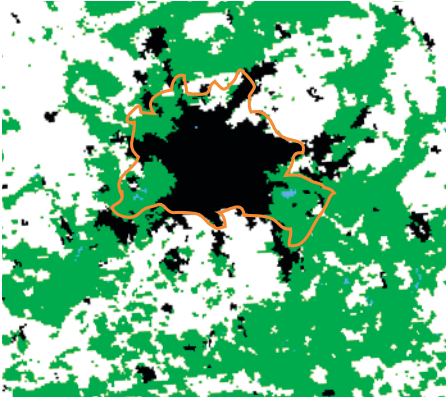


Illustration: Christian Fietner

of rivers as an indirect supply source, mitigation measures including upgrading wastewater purification plants, protecting areas around water supply wells, and cleaning stormwater at the source by soil filtering are in operation. Despite threats to water quality, Berlin's water exceeds the standards set by the German drinking water ordinance and is considered to be generally good.

Successful water demand management

The water authorities in West Germany (including West Berlin) introduced extensive programs in the 1980s to reduce per capita water consumption in an effort to reduce both groundwater withdrawal and water-system infrastructure investments. These programs include fit-to-purpose water pricing, awareness-raising campaigns and instructions for water saving, temporary subsidies for the purchase and installation of water-saving equipment, and technical innovations to diminish leakages. These measures have succeeded in reducing Berlin's per capita water consumption from 250 liters per person per day in 1980 to 112 L/p/d in 2008.

Current water challenges

- EU Water Directive Frameworks has strict requirements on quality of water, for example, reduction of nitrates and phosphates in wastewater treatment effluent.
- Treated wastewater released into rivers that are used as indirect water sources is challenging in terms of water quality management.
- Increasing occurrence of heavy rainfall are causing combined sewer overflows to rivers and short-term urban flooding (not yet an outstanding problem).

- Expectations continue to rise regarding the ability to use rivers and lakes for bathing, shipping, tourism, etc.

Major strategies for urban water management

- Permanently securing drinking water quality through recovery of water from the area within city limits; no chemicals used at waterworks.
- Sustaining high water quality of rivers, lakes, and groundwater; utilizing a common nitrate-reduction strategy in the river catchments together with neighboring regions.
- Decentralized stormwater management: catch, treat and use stormwater where it falls, preventing it from discharging to surface waters and sewers.
- Use stormwater management for multiple functions, such as cooling buildings, mitigating urban heat island effects, urban flood control, amenities, biodiversity, etc.
- Prioritize evaporation of stormwater to compensate for the impaired natural water cycle and to mitigate urban heat islands.
- Prioritize use of stormwater for non-drinking purposes, such as cooling, irrigation and maintenance of urban blue-green spaces
- New emphasis on infiltration, retention, and detention of stormwater locally with the increasing awareness of urban flooding after heavy rain in recent years, to prevent combined sewer overflow and store stormwater locally for later use, referred to as "sponge city" approach.

Figure 12. Green façade of the Institute of Physics in Berlin-Adlershof. Rainwater harvested from roofs is stored in tanks and used to irrigate a façade greening system and to generate evaporative cooling effects. Extra water is collected in a pond in the building's courtyard, allowing the water to either evaporate or drain into the ground.



Photo by Andreas [FranzKaver] Stiib

- Non-conventional water (stormwater and greywater) as “service water” for non-drinking use, such as domestic applications (watering, cleaning, toilet flushing, and laundry) and commercial and industrial uses (e.g., cooling, washing, and cleaning systems).

Green infrastructure approach to water

Because Berlin’s urban water management strategies have a strong environmental focus, the city has been trying to strengthen its green infrastructure approach and green solutions. Green infrastructure approaches are evaluated to have a medium role in urban water management.

Bank filtration–based water supply

Riverbank filtration is the process of collecting water from wells or infiltration galleries located near the bank of a river. The riverbed/bank acts as a natural filter to clean the river water before it enters the aquifer. Treated wastewater is used to replenish surface water, which in turn recharges aquifers, replacing the quantity of water withdrawn from the city’s groundwater sources. Most rivers contain less than 10% treated wastewater. It is estimated that more than two-thirds of raw water withdrawn for water supply in Berlin contains bank-filtered water or artificially recharged surface water.

Green roofs and green facades

Green roofs and green facades have been increasingly implemented in Berlin since the 1970s thanks to greening campaigns and programs such as the Courtyard Greening Program, which aims to mitigate urban problems and adopt environmentally friendly living, and the Urban Ecology Model Projects program, which aims to develop technologies and new processes of ecological, economic, and innovative buildings through role-model building projects. Green roofs were implemented with subsidies from 1984 to 1994, resulting in approximately 65,750 m² of green roofs. Currently, 14% (approximately 10 million m²) of all new urban development in Berlin incorporates green roofs, although it is voluntary. About 80% of the green roofs are



Figure 13. Rainwater retention basin at Potsdamer Platz. A combination of green and non-green roofs harvest rainwater, which then flows down through the site’s buildings and is used for toilet flushing, irrigation, and fire systems. Excess water flows into the pools and canals of the outdoor waterscape and underground tanks for storage and then feeds into a succession of narrow pools and a larger pond. Planted purification biotopes serve to filter and circulate the water that runs along streets and walkways.

extensive green roofs, with about 10 cm substratum. The goal of applying green roofs and green facades to buildings is to enhance the quality of amenities, improve microclimate, urban biodiversity and property value, and reduce urban heat island effects and stormwater runoff. Green roofs are often linked with other forms of stormwater management, such as overflow of excess roof runoff to ponds, use of excess water as service water, and infiltrating excess water to recharge groundwater (for further information, please refer to BSUD, 2010).

Implementation of and barriers to green measures

In Berlin, green measures for stormwater management are first implemented through pilot projects. Innovative techni-



Figure 14. Swale/gutter at Potsdamer Platz.

cal systems and processes are developed and documented through these pilot projects. These are further incorporated into technical guidelines, standards, and regulations in order to scale green measures up to the city level. Research and monitoring programs are often combined with these pilot projects through collaboration among city administrations, the state government, Berlin Water Company, universities and research institutes, and companies. Cooperation among city administrations and stakeholders has intensified over the past 20 years.

Major implementation measures

- Pilot projects, such as the Urban Ecology Model Projects and the Courtyard Greening Program
- Law-based regulation of stormwater management, for example, the “rainwater management at the source” requirement of the Federal Water Act
- New criteria, indicators, and guidelines that may be binding in planning and design, such as the Ecological Criteria for Building Projects/Competitions; the Biotope Area Factor, stipulating the proportion of a property to be vegetated; Rainwater Management Concepts guidelines (BSUD, 2010); and Innovative Water Concepts guidelines (BSUD, 2007)
- Incentives: in Berlin the rainwater fee is €1.804/m²/year (water discharged

to the sewage system). This rainwater fee is waived or reduced for properties with permeable or semi-permeable surfaces. Green roof areas pay 50% of the rainwater fee.

Identified barriers to implementing green measures

Technical barriers

- Conflicting uses of the water system make it difficult to implement measures to achieve water quality goals.
- Difficultly applying new solutions and measures developed through scientific studies and pilot projects due to challenges to adapting the existing legislative framework to the new approaches.
- Difficulty accounting for the non-monetary benefits of green solutions, such as biodiversity, amenities, health and so on.

Institutional barriers

- It is difficult and time-consuming to coordinate the large numbers of stakeholders necessary for a successful project.
- Sometimes the stakeholders have different levels of knowledge and ideas concerning green solutions, so it is difficult to communicate or convince them in the need for these measures.
- Limited human resources: the needed actors from other departments or institutions are not always available.

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Figure 15. Melbourne with view of Yarra River and Bay City.

Urban water management

Around 80% of Melbourne’s drinking (potable) water is sourced from strictly preserved forest water catchments in the Yarra Ranges outside of Melbourne. Water is transferred from reservoirs to the city by a pipe system. The groundwater is saline and shallow

and therefore not suitable as a drinking water supply. Melbourne markedly improved its water-saving efforts during the 1997–2009 drought. These efforts resulted in significant reduction of water use—58% reduction for residential water consumption and 20% for city council water consumption since 2000. Various actions and measures include setting

Country & city status	Capital the state of Victoria and 2nd most populous city of Australia
City area (km²)	37.7 (City of Melbourne in 2015)
Population (millions)	0.13 (City of Melbourne in 2015)
GI and open space coverage	12.7% (parks and reserves in 2015)
Annual precipitation (mm)	650; distributed relatively evenly throughout the year, though rainfall has annual variation
Main surface water & role for supply	Yarra River, Maribyrnong River, and Moonee Ponds Creek (a tributary of Yarra River); the upstream of Yarra is a source of drinking water, and its supply areas include City of Melbourne; the city is located at the bottom of the Yarra catchment, where it enters Port Phillip Bay
Honors on sustainability	For more than 15 years, the city has aimed to be one of the world’s most sustainable cities; Melbourne is participating in the 100 Resilient cities initiative, funded by the Rockefeller Foundation

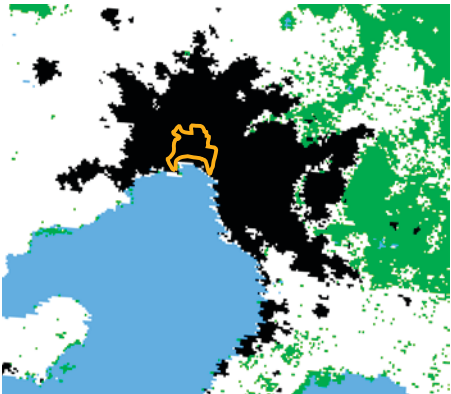


Illustration: Christian Fernet



Figure 16. Howard Street Reserve rain garden. The rain garden captures stormwater runoff from the road and cleans it before it enters the waterways.

water-conservation targets; educating households; implementing efficient water-saving fittings and appliances; restricting garden irrigation and encouraging use of efficient plant species; and defining fit-for-purpose water use to allow use of alternative water sources. The city has implemented a number of stormwater capture projects to provide water for irrigation. Rainwater harvesting ranks first in Melbourne's alternative water source hierarchy. According to rough estimations, rainwater harvesting could provide over half the water needs of the city when combined with demand management practices. The state government built a desalination plant to augment water supplies near the end of the drought, but the plant was not yet in use by the time of this study. Rainwater is collected from many private buildings for irrigation and toilet flushing. Some local areas in the city are developing a third pipe network to supply water reclaimed from rainwater (The Melbourne Cricket Ground, University of Melbourne, Fishermans Bend).

Current water challenges

- Effects of climate change challenge the water supply: The city experienced 13 years of drought, from 1997 to 2009. Decline of annual rainfall, higher temperatures, and higher evaporation rates decrease runoff into rivers and reservoirs; heatwaves caused loss of life.

- Water is needed to irrigate green infrastructure and plays a role in cooling the city.
- Lack of environmental flows puts pressure on certain sections of rivers in the region of Victoria, of which the City of Melbourne is a part; urban stormwater runoff is damaging the ecology of freshwater resources.
- Increasing population is expected to result in increased water demand (additional 80% population by 2030).
- The limited capacity of the current drainage infrastructure is also challenged by climate change.

Major strategies for urban water management

"A healthy city in a healthy catchment" embodies Melbourne's vision for its urban future. The city has practiced total water-cycle management since 2002, supported by the Total Watermark: City as a Catchment strategy (updated 2004, 2009, 2014) and the Water Sensitive Urban Design (WSUD) Guidelines (2005). The Total Watermark strategy recognizes "the important roles of the natural and man-made catchments, including roads, roofs and impermeable surfaces, to minimize potable water consumption, reduce wastewater generation and lessen the

Table 3: Focus areas and targets of Total Watermark: City as Catchment strategy (City of Melbourne, 2014)

Focus areas	Targets	Measurement (baseline year 2000)
Climate change and flood adaptation (a resilient and safe city that is adapted to current and future extreme weather events)	<ul style="list-style-type: none"> • Adaptation and flood risk embedded into planning process • Melbourne municipality has an aware and prepared community 	<ul style="list-style-type: none"> • Level to which climate change adaptation is incorporated into urban planning initiatives • Level of awareness of residents and businesses about climate change and flood risks
Water for Livability (a water cycle that supports the health, well-being, and enjoyment of everyone who lives, works, visits, and plays across and beyond the municipality of Melbourne)	<ul style="list-style-type: none"> • Water and livability embedded in planning processes • Access to waterways and public open spaces help support a healthy population 	<ul style="list-style-type: none"> • Implementation of City of Melbourne's Open Space Strategy • Increased frequency and diversity of water-based public activity
Water for the Environment (water managed for biodiversity, healthy public open spaces, and clean waterways)	<ul style="list-style-type: none"> • Our major waterways are healthy and clean • Soil moisture supports a healthy urban forest • Optimize stormwater quality 	<ul style="list-style-type: none"> • Health of waterways (measured by Melbourne Water) • Decreased runoff (modeled data) • Increased infiltration (modeled data) • Reduction in total nitrogen contributed to waterways from the municipality of Melbourne's catchment to 20% (2018) and 30% (2030)
Water use (efficient use of fit-for-purpose water contributes to the improved sustainability of Melbourne's water supply system)	<ul style="list-style-type: none"> • Optimize fit-for-purpose water use • Water supply infrastructure is planned for current and future demand 	<ul style="list-style-type: none"> • Council's total water use sourced from alternative water sources increased to 30% (2018) and 50% (2030) • Municipality's total water use sourced from alternative sources: 8% (2018) and 20% (2030)

impact of stormwater discharges on receiving waters.” The strategy emphasizes water reuse and protection of waterways from runoff pollution. Reusing storm water and retaining stormwater before it enters the waterways and sewers are priorities. Major strategies with focus areas and targets are outlined in Table 3.

Green infrastructure approach to water

Green infrastructure plays a relatively strong role in urban water management. In recent years, Melbourne has begun considering green infrastructure for flood control and climate adaptation. The city is now designing stormwater harvesting tanks that can quickly release stored water into stormwater systems before the rain if a heavy downpour is expected. In the new Elizabeth Street Catchment Integrated Water Cycle Management Plan (2015), green infrastructure and stormwater harvesting upstream in the Elizabeth Street catchment is recommended to reduce flooding downstream of the catchment.

Water sensitive urban design (WSUD)

WSUD is a term used in Australia that is similar to sustainable urban drainage system, with a focus on stormwater management. Three key elements of WSUD are access to diverse water sources supported by fit-for-purpose principles; provision of ecosystem services for the built and natural environment; and community engagement. At the local scale, landscapes can be categorized as either a “source” or a “sink” for stormwater, and water-cycle links can be made between these landscapes. By 2014, the City of Melbourne implemented water harvesting systems in 26 sites at various scales and under various ownership. WSUD guidelines developed by the city council (2005) provide tools and resources to support implementation of best practices. The city’s solutions include raingardens, tree pits (Figure 19), street greening, and stormwater harvesting in parks and wetlands. Waterways and urban forests are an important part of Melbourne’s identity, and these resources are believed to enhance citizens’ health and the city’s amenities. Green infrastructure, including water systems and public open



Figure 17. Melbourne with view of Yarra and green space docklands.

spaces, is incorporated through planning into the built environment where possible to retain floodwater, mitigate urban heat island effects, provide visual contact and physical use, and create healthy waterways by improving water quality. Some local community groups are undertaking revegetation schemes along rivers to enhance the rivers’ ecological performance.

Zero potable water use in council-managed parks

Green infrastructure in the city requires irrigation because of drought, hot summers, and heat waves. Therefore, Melbourne is exploring ways to capture water for irrigation in parks and streets to make them drought resilient. The city aims at 100% percent reduction in potable water use in council-managed parks. This will be achieved through a potable water offset scheme and by changing to a drought-tolerant landscape, as well as using appropriate volumes of water for irrigation to maintain vegetation in optimum health. A large portion of this water must be delivered from alternative sources, primarily through stormwater harvesting. The city has implemented an extensive drought-proofing program in open spaces, including converting turf to warm season grasses, installation of stormwater harvesting tanks, and major changes to irrigation practices and systems .

Figure 18. Royal Park Wetland (constructed in 2005). The wetland is designed to treat and recycle stormwater run-off from the roads, rooftops, and gutters of surrounding suburbs. A natural filter, with banks densely covered by native Australian plants that treat and clean stormwater through natural biological processes. The processed clean water is used to irrigate extensive areas of Royal Park in summer, while the remainder flows through to Port Phillip Bay.





Figure 19. Tree pit installed in the central city since 2006. It is a specially designed tree planting system that removes pollution from stormwater before it enters the waterways. It also provides passive irrigation for the tree, reducing the need for manual watering.

Implementation of and barriers to green measures

Endorsed strategies have been important for green infrastructure implementation in Melbourne, for example, the Total Watermark and Climate Adaptation strategies. Financial support from higher levels of government (state government and federal government), and other sources has been very helpful for the implementation of stormwater harvesting systems. For example, the federal government granted an implementation budget for stormwater harvesting schemes in Fitzroy Gardens, Birrarung Marr, and Queen Victoria Gardens. In return, the city must provide evidence of return on investment for this funding (i.e., water savings).

Major implementation measures

- Demonstration projects in the city council–managed areas
- WSUD guidelines and planning regulations targeting non-council–managed areas to incorporate integrated water-cycle management design principles into drainage plans prior to receiving planning approval
- Collaboration with a broad group of stakeholders (e.g., state government, universities, Cooperative Research Centre) and citizens in implementing Total Watermarks: City as Catchment strategy
- Development of catchment management strategies/plans: The Elizabeth Street catchment plan was approved

by the city council in 2015. The private sector was engaged to recommend changes during development of the strategy.

- Integrating “City as a Catchment” strategy with other relevant strategies and programs of the city, such as Urban Forest Strategy, Open Space Strategy, Urban Ecology and Biodiversity Strategy, and Inner Melbourne Action Plan.

Identified barriers to implementing green measures

Technical barriers

- The implementation of green infrastructure at the project level may conflict with issues of existing infrastructure that require special attention, for example, consideration of traffic sight lines, crossovers and clearance distances, space requirements for pedestrians and parking, avoiding tripping hazards, and prevention of vehicles from damaging or dropping into green infrastructure.
- Cost of implementing watering requirements in long dry spells may be high.

Institutional barriers

- Multi-disciplinary teams are required to deliver effective green infrastructure projects, but there are challenges in forging partnerships among a large number of organizations.
- Community opinions differ about water use and whether potable water should be used for irrigation.

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Figure 20. City of Philadelphia.

Urban water management

Philadelphia’s drinking water is sourced from its rivers, which serve roughly the whole area of the city. The Philadelphia Water Department (PWD) provides both water supply and wastewater services to the city and to some surrounding counties. The wastewater service covers an area three times bigger than the area of the city. The combined sewers cover an area of about 40,000 acres (166 km2),

or about 60% of the city’s sewerage area, encompassing more than three-fourths of the city’s residents. Like many other American cities, Philadelphia faces a set of complex environmental, demographic, and financial challenges set against customer’s expanding expectations for a safe and affordable water supply, waste- and stormwater treatment, flood protection, and clean, attractive, fishable and swimmable rivers.

Country & city status	The largest city and the economic and cultural center of Pennsylvania, United States
City area (km²)	367
Population (millions)	1.6 (in 2013)
GI and open space coverage	46% (parks and reserves in 2015)
Annual precipitation (mm)	1045; distributed evenly throughout the year
Main surface water & role for supply	The city is in the downstream catchment of the Delaware and Schuylkill Rivers; rivers are source of water supply
Honors on sustainability	The first city in the United States with a long-term green infrastructure plan; top performance on green infrastructure among 14 Northern American cities assessed by NRDC in 2011

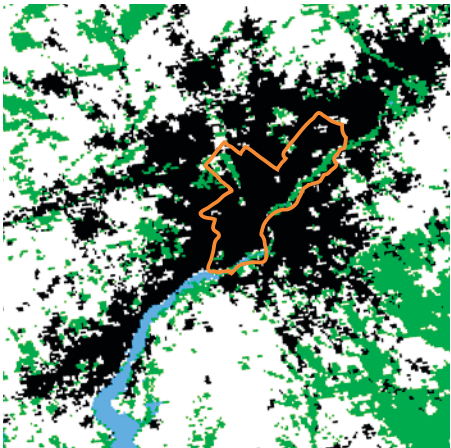


Illustration: Christian Fentner



Figure 21. Columbus Square stormwater planters. They are designed to manage street and sidewalk stormwater runoff by providing storage, infiltration, and evapotranspiration or detention and slow-release when underlying soils do not allow for infiltration. Excess runoff is directed into an overflow pipe connected to the existing combined sewer pipe.

Figure 22. Porous street before and after, Percy Street, Philadelphia. The porous street replaces traditional impervious asphalt to allow stormwater to infiltrate the surface and be stored in a stone bed until it can be absorbed by the soil. It reduces the amount of polluted runoff entering city sewers and helps keep homeowners' basements dry where flooding often previously occurred.



Current water challenges

- The Federal Clean Water Act (1972) and National CSO Control Policy's stringent requirements for combined sewer overflow (CSO) mitigation; CSO impairs water quality, threatens recreational use, and degrades waterways and aquatic habitats, resulting in a lack of base flow. Around Philadelphia, only one-third of water in rivers consists of base flow, compared to two-thirds in natural rivers; the rest is treated wastewater discharge
- Dramatic flow fluctuations between dry and wet weather
- Increasing need for flood control and adaptation to climate change

Major strategies for urban water management

In 2009, the mayor at the time set a vision for making Philadelphia the greenest city in America, and the Office of Sustainability was established to help create a blueprint for realizing this goal. City officials believe that a green identity will help the city flourish by attracting more residents and more revenue to the city, increase property values, enhance awareness of the benefits of green stormwater infrastructure (GSI), and benefit the environment as a whole. The major strategies for urban water management are based on this concept and are elaborated in the Green City, Clean Water Plan (2011). The plan involves an investment of US\$2.4 billion within 25 years, of which at least US\$1.67 billion is slated for GSI. The plan is based on a thorough analysis comparing several alternative solutions and includes various monitoring programs to

assess system performance and impact on groundwater. Within the available budget and 25-year timeframe, the decentralized approach is expected to provide maximum return in benefits to the public and the environment for all four area watersheds, with benefits accruing immediately. In comparison, the traditional infrastructure approach focused on a single purpose of CSO reduction in only one watershed. Major strategies include the following:

- Apply a green approach (land-water-infrastructure) for CSO control. Manage stormwater at the source through improved land management practices, directly restore aquatic habitat to support living resources, and upgrade old infrastructure systems to further reduce CSO.
- Eliminate 80%–90% of pollutants mainly through large-scale (at least one-third of the impervious combined sewer system area) implementation of GSI for on-site control of stormwater runoff, which otherwise runs into the combined sewer system and becomes polluted.
- Utilize rainwater as a resource by reusing and recharging groundwater aquifers rather than piping rainwater away to the already stressed tributaries. Prioritize infiltrating and re-using stormwater over detention and discharge of stormwater.
- Comprehensively manage watershed by working with watershed stakeholders for long-term improvement of water quality and habitat along the cities' waterways.
- Besides the Green City, Clean Water program, the city is committed to developing parallel programs for flood management and climate adaptation.



Green infrastructure approach to water

GSI plays a strong role in urban water management. It forms the backbone of the city's commitment to meeting the requirements of the Clean Water Act and National CSO Control Policy. GSI includes a range of soil-water-plant systems (e.g., bio-retention planters in sidewalks and parking lots, green roofs, and roof leaders that run off into raingardens) that intercept, infiltrate, and evaporate stormwater, in some cases releasing a portion of it slowly back into the sewer system. GSI is used to mimic natural runoff processes to achieve a thriving ecosystem. It is applied for renewal and expansion projects.

Managing one inch of rain at the source

The city's stormwater regulations were updated in 2006 to require on-site management of the first inch (25.4 mm) of rainfall in all new development and re-development projects larger than 15,000 square feet (1,394 m²). The on-site management must be achieved through infiltration, evapotranspiration, or harvesting. If infiltration is technically impossible, some (20% in combined sewer areas) or all (100% in separate sewer areas) of the non-infiltrated portion of the first inch of runoff should be routed to an approved "volume reducing" stormwater management feature, such as planter boxes, bioretention with underdrains, green roofs, etc.

"Greened Acre" as measurement for GSI implementation

"Greened Acre" is a concept used as an important performance goal and measurement of progress. A greened acre is an acre (4,047 m²) of impervious cover reconfigured to utilize GSI to manage the first inch (up to 1.5 inches) of stormwater runoff from that acre. This includes the area of the stormwater management feature itself as well as the area which drains into it. One greened acre corresponds to about 103 m³ of stormwater managed by well-functioning GSI. The state-approved plan requires at least 9,564 greened acres over the next 25 years, with measurements every 5 years to track progress toward that goal.



Figure 23. Cliveden Park raingarden. The raingarden provides beautiful landscaping while managing stormwater from nearby streets and protecting local streams.

Implementation of and barriers to green measures

The city's initial focus is on publicly owned impervious cover (45% of the impervious land area of the city) and the larger commercial properties. For example, the primary focus is streets and sidewalks, which account for 38% of impervious cover in the combined sewer areas. GSI is incorporated whenever utility and road work is planned. Green programs are applied to implement greened acres in non-publicly owned land as well. Many of these programs have technical guidelines and associated implementation tools – including policy changes, regulatory tools, funding commitments and incentives. As the leading actor of green infrastructure implementation, the Philadelphia Water Department (PWD) coordinates extensively with other city agencies to incorporate green infrastructure designs as standard practice in city projects. Non-governmental organizations such as the Natural Resource Defense Council (NRDC), Penn Future, and Clean Water Action have supported these efforts with work and documents. Supports from nonprofit, philanthropic, and academic entities are and will continue to be instru-



Figure 24. Stormwater Bumpout, East Falls. The stormwater bumpout can store, infiltrate, and take up (evapotranspiration by plants) road stormwater, helping to reduce runoff and prevent combined sewer overflows into rivers and streams, as well as helping with traffic calming.

mental in the successful realization of the program. Additionally, PWD's commitment to this program has increased the need for planning and design resources, resulting in a significant increase in the number of contracts between the city and the private sector.

Major implementation measures

- Update of stormwater regulations in 2010 to take advantage of private investment in green infrastructure: stormwater fee based on parcel make-up, or the degree of surface sealing, rather than meter size for nonresidential properties (including parking lots), where 80% of a property's charge is based on its impervious surface area and 20% on its gross area; a maximum discharge rate to combined sewer system; slow release requirements for runoff from heavy rainfall to channels; Operation and Maintenance Agreement (O&M) that requires developers to submit stormwater plans (with maintenance strategies) before a building permit is released.
- GSI incentives to non-residential properties bigger than 5 ha, giving US\$100,000 per ha of land with management of the first inch of rain. Other incentives such as free design assistance and green roof tax credits are provided.
- Green programs, such as Green Streets, Green School, Green Roof, and waterway-restoration programs, with GSI demonstration projects to garner

public support and test different GSI technical approaches.

Identified barriers to implementing green measures

Technical barriers

- The cost of implementing GSI in small properties is high. This presents a challenge to the "stormwater fee" measure, which aims to encourage private properties to install GSI. Therefore, PWD is seeking to enhance incentives to further intensify their use.
- The cost of GSI in streetscape projects is even higher (three times), because of infrastructure costs.

Institutional barriers

- Because of the magnitude of the city's commitment to GSI, the difficulties lie in the logistics, e.g. land ownership, partner coordination and needs, scheduling alignment, community perceptions. None of these is insurmountable, but each brings along with it a potential cost—be it monetary, schedule, or acceptance.
- There is no incentive for residential properties. PWD lacks the capacity to do outreach to mobilize home owners to apply GSI.

Further links and references

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Figure 25. Wind and solar street lights.

Urban water management

The local aquifer is saline and the ground-water level is about one meter below-ground. Groundwater is not suitable as a drinking water source or for watering green spaces. All drinking water needs to be transferred from the water supply system of Tianjin Binhai New Area outside of the eco-city. Available water resources

include groundwater transferred from surrounding regions, supply water from waterworks of surrounding regions, river water transferred from Luan River 234 km away, South-North-Water-Transfer project water, and desalinated seawater. A new wastewater treatment plant has been built to treat wastewater from the Eco-city and neighboring districts. A separate stormwater drainage system

Country & city status	Newly built town of Tianjin City, China; 50 km east of Tianjin Central City; a state-level collaboration project between China and Singapore since 2007
City area (km ²)	34
Population (millions)	0.35 (planned population)
GI and open space coverage	>40% green space ratio
Annual precipitation (mm)	603; 60% falling in July and August
Main surface water & role for supply	The old course of Ji Canal & Jing Lake (Yingcheng Reservoir); rivers and lakes not as source water for supply; the city is near Bohai Bay
Honors on sustainability	The first eco-city implemented in China, with high sustainability goals based on key performance indicators (KPIs) (Table 4); in 2016, the City was selected as one of the pilot cities for China's Sponge City demonstration

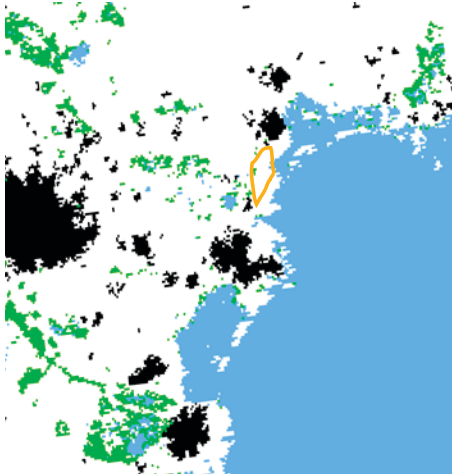


Illustration: Christian Ferner



Figure 26. Rainbow bridge as the access road to Sino-Singapore Eco-city.

has a service level of 3-year rain events. Many green and blue spaces are planned in the city to provide ecosystem services for both ecology and quality of life. All green spaces must be equipped with a saline drainage layer belowground. Much freshwater is needed to create and maintain these green-blue spaces. The city's Construction Bureau is responsible for water management in collaboration with the City Management Bureau and Environmental Protection Bureau.

Current water challenges

- Lack of local water resources: relatively low precipitation; saline and shallow groundwater not suitable for supply
- The city has high standards for livability and ecological environment supported by green-blue spaces; maintenance of these green-blue spaces puts extra demand on water supply

Major strategies for urban water management

- Reducing tap water demand through use of non-conventional water such as reclaimed water and stormwater
- Applying a tiered system based on fit-for-purpose water quality for water supply. Two separated supply pipe systems: high-quality drinking water and reclaimed water for green space irrigation
- Stormwater is collected and utilized to add into water landscapes and wetlands
- Other strategies include establishing a circulation system among the water bodies within the landscape of the city, strengthening hydro-ecological restoration and surface water conservation, and prohibiting abstraction of groundwater to avoid land subsidence

Table 4. Examples of major KPIs.

Quantitative KPIs	Qualitative KPIs
<ul style="list-style-type: none"> • net zero loss of natural wetlands • 100% of green buildings • proportion of public housing no less than 20% • renewable energy usage no less than 20% by 2020 • per capita domestic water consumption no more than 120 L/p/d • water supply from non-conventional sources no less than 50% by 2020 • wastewater treatment rate 100% 	<ul style="list-style-type: none"> • advocating ecological safety • green consumption and low carbon operation • advancing innovation and anti-pollution policies • highlighting the cultural character of river estuarine • strengthening recycling economy

Figure 27. Site before development; one third of the area was previously used for salt production based on evaporation of seawater.



Green infrastructure approach to water

Green infrastructure plays a medium role in urban water management. Artificial wetlands are created to cleanse collected stormwater before feeding it into water landscapes. Green-blue spaces are maintained by non-conventional water (reclaimed water and stormwater), contributing to recycling of local water resources. After the national Sponge City guidelines were launched in late 2014, runoff peak flow reduction and stormwater detention and retention by low impact development became new priorities.

Wetlands cleanse collected stormwater for use in water landscapes

In the original master plan, the overall solution for stormwater management was to drain the runoff as fast as possible to the water landscapes, with the least possible infiltration on the way. The city is zoned into four stormwater drainage zones, each with a stormwater pump station at the lowest point combined with an artificial wetland. Permeable pavers with belowground separate stormwater pipes collect stormwater runoff from all slow traffic paths and stormwater overflows from roadside greenbelts into wetlands at the four stormwater pump stations. Collected stormwater is cleansed by the wetlands before it is pumped into the old course of the Ji Canal to maintain the water scenery. The wetlands also create small habitats and improve biodiversity. The stormwater runoff from the surrounding areas of Jing Lake and Eco-island is drained from the surface into the Jing Lake.

Green space irrigation with non-conventional water

The city's new reclaimed water plant will produce 50,000 m³ of reclaimed water per day. According to the master plan, reclaimed water pipes are rolled out below green spaces all over the city, mainly for irrigation. A small portion of the reclaimed water will be used for toilet flushing in some buildings. A pilot project collects roof or surface runoff from seven buildings and their areas for green space irrigation or creating small-scale waterscapes nearby. The city aims to use at least 70% native plant species to reduce the amount of water used for irrigation. A substantial part of the city is green-blue

spaces, and thus watering green spaces with non-conventional water will save much tap water.

Sponge City policy sets new goals for stormwater management

In response to the Sponge City policy, the city has updated its goals with Sponge City principles whenever possible to stay at the front of eco-city practices. Runoff control and on-site infiltration are emphasized. However, it is technically challenging for the city to develop sunken green space for infiltration because the cost of developing the saline drainage layer and top soil layer rises as the project goes deeper. In addition, Sponge City's focus on infiltration and retention at the source is not in line with the City's earlier strategy of draining stormwater through separate pipes into landscape waters. However, considering that the infiltration process can potentially mitigate soil and water salinity, the city plans to balance stormwater harvesting and infiltration in future practice. The city is adopting Sponge City concepts into the revised Green Building Standards and has started a few pilot projects with low-impact development solutions, such as infiltrating stormwater using sunken green space and swales. There are also demonstration projects in public open spaces, where surface runoff is harvested at a small scale



Figure 28. Wetland at Qingtuozi rainwater pumping station. Collected stormwater runoff is cleaned before it is pumped into waterscapes.

Figure 29. A stormwater storage tank under construction in Qingnian Park.

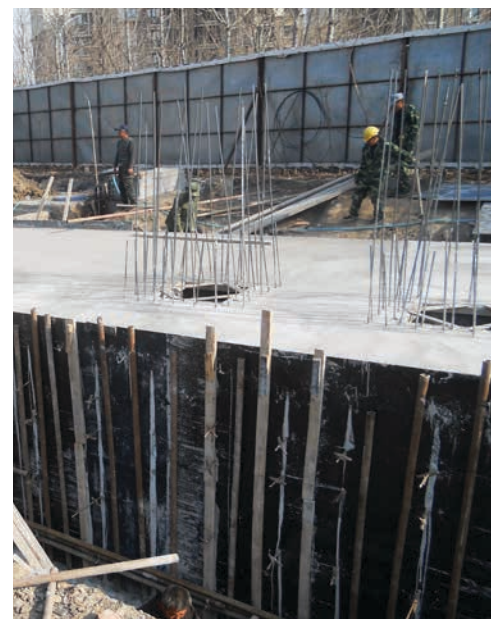


Photo: Ren Na

and used for small water landscapes. Due to water quality concerns, the potential of using collected surface runoff for watering green spaces at a larger scale is still being explored.

Implementation of and barriers to green measures

The eco-city implements green infrastructure primarily through government-funded demonstration projects in public areas and by integrating planning concepts and goals into design standards to guide developers' practice. The Master Plan and KPIs, which include green infrastructure and water management goals, are also important measures for implementation. This is managed by the Construction Bureau in cooperation with the city's construction-project management company, which is responsible for developing, managing, and maintaining public green spaces. Developers who follow these design standards will benefit based on a rating system. City administrators encourage eco-innovation and select implementation solutions suggested by companies, based mainly on cost-effectiveness, maintenance requirements, and feasibility within the local context. Green infrastructure-based water management projects have increased the need for cross-sectorial coordination within city administration and with relevant non-governmental organizations.

Major implementation measures

- City-wide strategies and KPIs focusing on non-conventional water supply for green infrastructure maintenance
- Design standards and rating systems to guide development on semi-private

land managed by developers, e.g., Green Building Standards promoting rainwater harvesting

- Government-funded demonstration projects in public areas

Technical barriers

- Difficult to implement stormwater management in low-lying areas due to high aquifers and saline groundwater.
- Due to the short rain season, the cost-benefit of the operation and aesthetics of green infrastructure-based measures is low.
- The cost is high for a large-scale application of green infrastructure-based stormwater management elements because the available facilities in the local market are expensive and sometimes quality is low.
- The city does not have adequate experience for the construction and maintenance of green infrastructure-based measures.

Institutional barriers

- The city lacks financial incentives.
- The city's construction-project management company lacks the management and maintenance capacity to assess the implemented green infrastructure-based stormwater management elements because of the already challenging task of maintaining vegetation in the harsh conditions. Their routine work focuses on scenic effects, recreation, and the feasibility of design solutions on saline land, while the link to water management is only a supplementary goal.
- Inter-sectorial and stakeholder collaboration occurred mainly before project construction, when projects need to be approved; more collaboration is needed in the implementation phase.

Figure 30. In Qingnian Park, the collected stormwater from the stormwater storage tank (Figure 29) is used for creating waterscapes.



Photo: Ren Na

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